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Science teachers' use of analogies: observations from classroom practice

David F. Treagust, Science and Mathematics Education Centre, Curtin University of Technology, Perth, Australia; Reinders Duit, Institute for Science Education, University of Kiel, Germany; Paul Joslin, Drake University, Des Moines, Iowa, USA and Ivo Lindauer, University of Northern Colorado, Greeley, Colorado, USA*

The study was designed to examine how science teachers used analogies during their regular teaching routines to enable students to comprehend scientific concepts. A total of 40 lessons taught by seven different teachers were observed and analysed using an interpretive research methodology to develop four generalized observations. In this study the science teachers used few analogies, though both simple and enriched types were observed in their teaching. Interviews following classroom observations revealed that the teachers were knowledgeable about some of the beneficial and detrimental aspects of analogy use, and they considered that they used both analogies and examples as a regular part of their teaching, though it was observed that often they did not differentiate between examples and analogies. The research suggests that effective use of analogies in regular classroom science teaching needs to be based on a well-prepared teaching repertoire of analogies, using specific content in specific contexts and for science teachers to have a view of learners as being responsible for constructing their own knowledge rather than being passive recipients of teacher-presented knowledge.

Introduction

Over the past decade there has been considerable interest among science educators about teaching and learning science through the use of analogies. For example, the thematic research of Clement (1987), the extensive studies in this field by Gentner (1980, 1983, 1988) and Gentner and Gentner (1983), the work of Glynn and his colleagues (Glynn 1989, Glynn *et al.* 1989), and the general model of analogy use by Zeitoun (1984) have provided both an empirical and theoretical base from which to conduct further studies. Many recent experimental studies in science education, for instance by Black and Solomon (1987), Dupin and Johsua (1989), Gabel and Sherwood (1984), Radford (1989), Sutula and Krajcik (1988) and Stavy (1991) illustrate the growing interest in this area of research among science educators.

There are many definitions of an analogy in the literature. In this study an analogy refers to comparisons of structures between domains. An analogy is a relation between parts of the structures of two conceptual domains and may be viewed as a comparison statement on the grounds that these structures bear some resemblance to one another. A classical analogy is the water flowing through pipelines for the electric circuit. In accordance with the use of terms in the work of

* Correspondence to: David F. Treagust, Science and Mathematics Education Centre, Curtin University of Technology, GPO Box U1987, Perth, Western Australia, 6001, Australia.

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Glynn *et al.* (1989), the analogue is the domain used as the basis for structural comparisons (e.g., the water circuit) and the target is the domain to be explained (e.g., the electric circuit).

Analogies and examples serve similar purposes in the learning process in that they both may be used to make the unfamiliar familiar. However, they can be differentiated in that analogies explicitly draw comparisons between parts of structures in an unfamiliar and a familiar domain while, on the other hand, examples from familiar domains illustrate features of a concept and serve as instances for that concept.

The role of analogies in the learning process has been analysed from different theoretical perspectives (Shapiro 1985, Vosniadou and Ortony 1989). Rumelhart and Norman (1981), for instance, have outlined a schema theory perspective in which processes of the evolution and creation of new schemata presuppose that there is a well-established schema available to function as an analogue domain, or a source domain as Rumelhart and Norman call it. New schemata, therefore, can be generated by analogy. The theoretical perspective involving schema theory coincides with the main aspects of a constructivist view of learning, a view of learning that has become a leading idea in science education as well as in education in general through the past decade. In the constructivist view of learning, students actively construct their knowledge on the basis of their already existing knowledge, and can do so either with or without social negotiation, rather than more or less passively taking in and storing provided pieces of knowledge.

More 'traditional' views of learning, such as the one underlying Gagné's (1970) approach, are also aware of the necessity to relate the unfamiliar to the familiar. But learning appears to be viewed mainly as a continuous chain of enlargements of knowledge, the learning process proceeding step by step. Accordingly, definitions are employed to point out in which way the new concept or principle is related to the already known. Examples serve the same purpose. The constructivist view admits that much learning may be seen in this enlargement way, but what is principally different in this view is that most learning is not simply an enlargement but a totally new construction of the already known. In the field of constructivism this type of learning is called *conceptual change learning* (see, for example, West and Pines 1985). Analogies appear to be valuable tools, especially in conceptual change learning. A certain 'two-way aspect' of analogies comes into play here; analogy relations between analogue and target are in principle always symmetrical so the analogue and target can change roles. In every use of an analogy, both the analogue and target are developed; learning to 'see' the target from the perspective of the analogue also provides new views of the latter.

In a review of the research on the role of analogies and metaphors in learning science, Duit (1991) writes that the advantages of analogies follow from their significance within a constructivist perspective of learning in that they are valuable tools in conceptual change learning because they open new perspectives; they may facilitate understanding the abstract by pointing to similarities in the real world; they may provide visualization of the abstract; they may incite students' interests and this may have a motivational function; and they encourage the teacher to take students' prior knowledge into consideration and subsequently may reveal alternative conceptions in areas already taught. However, Duit (in press) further emphasizes the point made by Glynn *et al.* (1989) that an analogy is a double-edged sword in that it may totally mislead learning since an analogy is never based on a total one-to-one fit

between analogue and target and analogical reasoning is only possible if the intended analogies are used by the students.

Research into analogy use in science education has tended either to involve working with teachers to help them use analogies in problem solving and subsequently to observe student understanding of concepts (for example, Clement 1987) or to examine how analogies are used in textbooks (for example, Curtis and Reigeluth 1984, Glynn *et al.* 1989). No research appears to have been reported which examined how science teachers in their regular teaching routines used analogies to help students comprehend concepts. A study on metaphors used by history teachers is the only one of a similar kind, but in another field, known to the authors (Tierney 1988). Consequently, the purpose of this investigation was to examine how science teachers used analogies as part of their regular teaching to help students learn concepts; no attempt was made to influence the teaching practices of the science teachers. This research with seven science teachers in one school should be considered as providing limited but important information about science teachers' use of analogies as part of their regular teaching.

Methodology

An interpretive research methodology (Erickson 1986, Merriam 1988) was used to investigate the nature and frequency of analogy use by science teachers. According to Merriam (1988) those conditions which define a case study are fulfilled in this investigation. These conditions are the nature of the research question, the lack of control over the observed phenomena by the researchers, the desired end-product being the description and interpretation of a contemporary phenomenon and the research involving the examination of science teachers in one school.

Sample

A high school science faculty in an Australian metropolitan area was involved in the study. Of the eight science teachers who comprised the science faculty, seven agreed to participate; a teacher in her first year of teaching wished not to be included in the study. All seven teachers had experience ranging from 8 to 20 years in the classroom and each previously had had a science education researcher in his or her classes. The teachers were informed that the research team of four persons was interested to learn, from observing lessons, the ways in which teachers made concepts easier for the students to understand. It was further explained that the researchers were interested to see how the teachers utilized examples, the textbooks, students' questions, and analogies or metaphors to make difficult concepts easier to understand. In total, the seven teachers were observed teaching seven different courses ranging from lower school science courses in grades 9 and 10 for students aged 14+ and 15+ years, to upper school science courses in grades 11 and 12 for students aged 16+ and 17+ years. The three lower school courses observed were 'Forces, Motion and Energy' and 'Chemical Change' in grade 10 and 'Forces in Nature' in grade 9. The upper school courses observed were in Physics, Chemistry, Biology, and Human Biology; lessons in all courses except Chemistry were observed in both grades 11 and 12. Three teachers were observed teaching both lower school science courses and upper

school courses; three teachers were observed teaching only upper school courses and one teacher was observed teaching only lower school courses.

Data sources and data collection procedures

Observations were made and data were collected during four consecutive weeks in August and September 1988. The researchers sat in the teacher's classroom and carefully recorded what happened during each lesson by writing field notes. These notes included verbal descriptions of the setting, the students, the teacher and teaching, the substance of what the teacher and/or students said – including some direct quotations from students and the teacher during and after the lesson, and the observers' comments including reactions, hunches, initial interpretations and working hypotheses (Merriam 1988, p. 98). In total, 40 lessons each of 50 minutes' duration were observed and detailed field notes were obtained.

At the end of the four-week period in the teachers' classrooms, each teacher was interviewed about his or her view of the use of analogies in teaching, as well as his or her views of students' learning in general. The questions discussed in the interviews were: (1) What do you think analogies are good for in teaching and learning science? (2) If you compare the use of analogies with other teaching methods, what are the advantages and disadvantages of analogies? (3) Do you use analogies in your science teaching? Frequently, seldom, not at all? Why do you think this is so? (4) When you are introducing a new concept, what is the way you usually proceed? (5) In your view what are the most important difficulties students have in learning science? (6) Do you usually take students' ideas (preconceptions) into consideration when teaching a new concept? How do you do this? and (7) If you had to give an analogy for students' learning, which one would you present? The interviews were intended to gain a deeper appreciation of what the teachers thought about analogy use in helping students understand complex concepts and of their views about how students learn.

Data analysis and interpretation

Analysis of data took place over the duration of the study. The research team met each week to discuss substantive and procedural aspects; the overall purpose of the team meetings was to construct a complete interpretation of the data which were formulated into generalized observations based on a decisive balance of evidence favouring such generalized observations from different teachers in a range of classes. Any discrepant counter-examples were identified and investigated. The validity and reliability of the generalized observations were carefully considered by triangulation using supportive data from as many sources (mainly the field notes from the lessons and discussions with the teachers) and among as many researchers as possible. As observations were framed, modified and supported they were grouped with other observations in a more general and inclusive form to develop four generalized observations.

Results

Of the four generalized observations, three are related primarily to the findings of classroom teaching while the fourth refers mainly to the outcomes of the interviews

with teachers. The findings reported as generalized observations were interpreted finally in terms of an assertion which may help to explain and interpret these teachers' use of analogies in their regular teaching as well as provide direction for future research involving science teaching with analogies.

1. Few analogies were used in the observed lessons

Based on data analysed from the 40 lessons observed, there were six clear indications of analogy use and these occurred in five separate lessons. The number of different science courses and the lessons observed being taught by the seven teachers are presented in table 1, together with the number of lessons in which teachers were observed to use analogies in their teaching.

Using the analysis of analogies described by Curtis and Reigeluth (1984), three of the six analogies observed in the science teaching were of the simple comparison type and/or were used in a limited way and three were enriched. In addition, several teachers used activities or gave examples where the analogical potential was not fully utilized. The use of analogies was defined as being enriched because the teachers not only carefully and clearly showed the relationship between the analogue and the target, but they also dealt with the analogy's limitations and explained common misunderstandings likely to occur with each analogy. The six analogies observed during the science lessons are described in table 2 in terms of the target concept, the analogue and the type of analogy used by the teacher.

2. Three analogies were of the simple comparison type

Three of the six instances where analogies were used by teachers in this study were of the simple comparison type. In a grade 12 Biology class, the teacher was discussing

Table 1. Observed science lessons by seven teachers showing presence of analogy use.

	Number of lessons observed Teachers						
Science course	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Physics 12*	4 (1)‡						
Physics 11				4 (2)			4
Biology 12					2	4 (1)	
Biology 11		2					
Human Biology 12							1
Human Biology 11					4 (1)		
Chemistry 11	2						
Forces, Motion and Energy 10		2					2
Forces in Nature 9		3	1				1
Chemical Change 10			3 (1)	1			
Total lessons per teacher	6	7	4	5	6	4	8

* Physics 12 denotes a grade 12 Physics class, etc.
‡ The presence of an analogy used in the lesson is indicated by a number in parentheses following the number of lessons.

Table 2. Analogies used in observed lessons showing target, analogue and type of analogy.

Science lesson	*Target*	*Analogue*	*Type of analogy*
Biology 12	Function of DNA	Lock and key model	Simple comparison
Human Biology 11	Genes on chromosomes	Pop-bead model	Simple comparison
Chemical Change 10	Behaviour of gas molecules	Marbles demonstration	Simple comparison
Physics 12	Half-life in radioactive decay	Lottery or dice throwing	Enriched
Physics 11	Electricity flow	Water flowing in pipes	Enriched
Physics 11	Electric field	Gravitational field	Enriched

mutations and identifying how these occur on genes of chromosomes. She explained 'a gene represents the smallest section of DNA that can code for the production of a protein (usually an enzyme). Thus a chromosome is really an assembly of hundreds of genes.' In response to a student question about DNA, the teacher explained that 'DNA is like a lock and key model' and went on to describe how 'a gene mutation is a change in a small section of DNA which codes for a particular protein'. There was no further discussion or use of this analogy which would appear to have the potential to help students with their understanding of this concept.

An analogy of considerable instructional potential was used in two lessons on genetics by another teacher of grade 11 Human Biology. He employed a pop-bead model as an analogue for chromosomes to show gamete formation in the outcomes of a monohybrid cross written on the blackboard. In this lesson, the teacher asked the students to 'use the beads to demostrate a cross of a homologous pair using each bead as a gene on a chromosome, and use a felt pen to mark an allele'. Various students were then asked to demonstrate what they had done. This part of the lesson was then related to the concept of meiosis. The use of the bead analogue appeared to work effectively in this lesson, based on students successfully completing monohybrid cross problems such as 'what is the probability that a child from a pure-bred male tongue roller and a female non-roller will be a tongue roller?' However, no attempts were made to explain any limitations or misleading aspects of this analogy. Without this explanation it is possible that the use of a black and yellow string of beads to demonstrate a homologous pair (one colour from each parent) may mislead students into believing that the genetic material carrier on a chromosome from one parent would be totally different from that of the other parent.

In a 10th grade class dealing with chemical change in gases, one teacher used a demonstration with marbles representing gas molecules but did not describe the features of the marbles which were to be compared with gas molecules. The students were left to make up this relationship for themselves.

3. Three analogies were enriched

The enriched use of analogies was observed on three occasions in two physics lessons by different teachers. Within the discussion of the concept of half-life in radioactive decay in a grade 12 Physics lesson, the teacher made several analogies between the target concept and probability-controlled games such as a lottery or dice throwing.

In this analogy the teacher explained that every nucleus has the same probability to be changed (to a nucleus of another element) in much the same way as every lottery player has the same chance of selecting the correct number. Not only was this particular analogy a perfect example of the working definition of a relation between parts of structures of two domains (the radioactive nuclear decay process and the selection of number in a lottery draw), it was also taught in an effective manner. The teacher discussed the limitations of this analogy with the students, namely that in nuclear decay, time is involved as chance within a certain period of time but in a lottery it is not. The teacher also briefly mentioned the aspect of luck. In further elaborating this analogy, the teacher employed the tossing coin analogy in order to explain that after two half-lives, not all nuclei have changed but there are still 25% left. He further explained some common misunderstandings of this point.

In a grade 11 Physics lesson on electricity, another teacher of physics employed two analogies. First, following an explanation of what makes electrons flow around an electric circuit and a discussion of both conventional current and electron flow, the teacher presented a traditional analogy between the electric circuit and a water circuit. In discussing the flow of water, the teacher attempted to convince the students that the water cannot get lost in the circuit. Later, fruitful as well as misleading aspects were discussed when the analogy was used to 'remedy' some major student misunderstandings.

In the second analogy used in this lesson, the teacher drew analogies between three different types of fields, namely the electric, the magnetic and the gravitational fields, with analogies between the electric and the gravitational fields being given much attention. An interesting switch between the fields was observed in that the teacher changed the roles of analogue and target several times, that is, he used the electric field to work out features of the gravitational field and vice versa. During this discussion, suggestions were sought from students and the teacher described some of the limitations of the field lines in that '[the field lines] are not real things, there is a field also between the field lines'.

This 'dual manner' of using analogies is also reported in the literature; for instance, Sigmund Freud tended to explain psychological and anthropological events by using one as an analogue for the other (see Dreistadt 1968, p. 105). As mentioned above, this dual manner is of great importance in the use of analogies in general; whenever an analogy is used, not only is the target developed but also the analogue because it may be viewed now from a new perspective, namely the perspective of the target (Bauer and Richter 1986).

4. Teachers differed in their understanding of analogies though advantages and disadvantages of analogies in teaching were recognized by all

While the observations of lessons indicated infrequent and usually non-elaborate use of analogies, five of the seven teachers interviewed were of the opinion that they used analogies frequently. However, the interviews suggested that most teachers used either examples or analogies in their teaching and that they did not always differentiate between analogies and examples. Given the similar purposes of analogies and examples in the learning process to make the unfamiliar familiar, this lack of differentiation is not surprising when the science teachers have had no formal education about analogy use in teaching. Nevertheless, some of the teachers'

descriptions of analogies contained aspects which were similar to those of the researchers. Some responses to the initial questions in the interview are as follows: 'Analogies are parallel situations, whereas examples are the situations'; 'An analogy needs to be based within the student's experience. An example may not be something they've experienced. An analogy must relate to their experience'; 'Analogies are as good as examples.... they are good for comparisons'. Based on these, and other interviewees' comments, it may be that the lack of differentiation between examples and analogies may help explain the contradiction between the observations of the study and the teachers' claims that they frequently used analogies to emphasize and illustrate aspects of their teaching.

Based on the interviews, the teachers were aware of many advantages and disadvantages of analogies though these were differently elaborated by individual teachers. One teacher commented that a disadvantage of an analogy is that 'there is a failure to show the limits of an analogy, for example, the spiral arrangements in the DNA molecule are not apparent from the analogy used'. He went on to explain other disadvantages: when 'teachers introduce the wrong concept sometimes [this] can cause misconceptions. For example, beads don't represent genes'. Another teacher explained the necessity to be cautious in introducing analogies since 'an analogy could confuse a person [being told about the analogy]. If one is not direct about the subject, a student's insight might take them on the wrong path'. Some analogies observed in lessons were given also in the interviews, for example, the water analogy of the electric circuit and the pop-bead analogy for chromosomes; other analogies were added when discussing advantages and disadvantages; for example, the bath sponge as an analogue for air compressibility and analogies between light, sound and water waves.

While none of the interviewees expressed analogue and target in terms of structural comparisons, in general their perceptions of using analogies in their teaching were similar to those advantages described in the literature (see Duit 1991). These analogies were generally seen as tools to help learning, especially in difficult topics where, for instance, prior misconceptions have to be overcome. Analogies were perceived to work because they drew comparisons between the analogue and the target domain. According to a comment from one of the teachers interviewed, 'analogies can relate to what the person already knows or what their [*sic*] interests are'. Analogies may be employed to relate abstract concepts to the real world and may relate the concepts under study to what is already known. They may also open new points of view in that they 'turn around the picture and give another perspective' as one teacher put it. Furthermore, analogies may promote visualization, that is, they may make something 'visible' which is invisible and abstract; for example, the water analogy of the electric circuit helps mental visualization of the invisible electric current.

Based on their understandings of analogies, the teachers knew that analogies may mislead students' learning because the features of analogue and target never totally fit. Another aspect of misguidance was mentioned by one teacher when pointing out that the analogue and the target are often quite different ontologically; for instance, water waves are very different from light waves. An important aspect was also mentioned by one teacher of physics, namely that the teacher (or the scientist) may be able to appreciate and understand the analogy whereas the student often does not. Similarly, some of the teachers were aware that a big conceptual jump may be necessary for students to understand an analogy.

Conclusion

The results of this study, completed with a small sample of seven staff members in a senior high school for four consecutive weeks, provide valuable, though tentative, data for researchers interested in how science teachers use analogies as part of their regular classroom practice. The teachers in this study were observed to use few analogies in their teaching and of the six analogies used, three were of a simple comparison type and three were enriched in that structural similarities between target and analogue were identified and limitations of the analogies were discussed. It seems apparent from the literature that analogies can be powerful tools to help learners understand complex and often abstract or non-observable concepts such as electric circuits or chromosomes. This is especially so when learning is viewed from a constructivist perspective in which conceptual change learning is a key aspect. In several instances where abstract or non-observable concepts were presented in class, analogies were used but, as indicated in this paper, the opportunities for making full use of the analogy as a learning/teaching tool were not always taken. The teachers generally responded positively, but cautiously, about the use of analogies in their teaching, though the research data show that they used examples more than analogies in their teaching and, in the minds of some of the teachers, these examples were not differentiated from analogies.

The study raises an important question as to whether or not the teachers in this study would improve their teaching of complex concepts if they used more analogies and used them more effectively. Based on the 40 lessons observed and interviews with the teachers, two points are very clear. First, since the more theoretical, abstract and non-observable concepts are taught to students in upper school classes or academic courses in grades 8–10 which are geared towards examined syllabi, the teachers do not tend to use the preferred teaching approach they espouse. Rather than taking into account students' preconceptions, for example, lessons are often introduced by definitions and illustrating examples, which might be termed the traditional way of teaching. In this style of teaching there is little opportunity to involve the students in constructing their own knowledge of a new concept in terms of a familiar analogue. Second, it would appear evident that in three instances of analogy use, the teachers were not using the analogy in an optimal way or describing limitations of its use, despite expressing a general understanding of these limitations in the interviews.

Consequently, based on the four generalized observations drawn from the data in this study, we would assert that effective use of analogies in regular classroom science teaching needs to be founded on a well-prepared teaching repertoire of analogies, using specific content in specific contexts, and for teachers to have a view of learners as constructing their own knowledge rather than being passive recipients of teacher-presented knowledge. We are examining this assertion in our future research using analogies in preservice and inservice science teacher education. Our first goal is to develop teaching materials which illustrate how specific analogies can be used effectively to help students comprehend complex science concepts.

References

Bauer, F. and Richter, V. (1986). Moglichkeiten und Grenzen der Nutzung von Analogien und Analogieschlüssen. *Physik in der Schule, 24* (10), 384–389.

BLACK, D. and SOLOMON, J. (1987). Can pupils use taught analogies for electric current? *School Science Review, 68*, 249–254.

CLEMENT, J. (1987). Overcoming students' misconceptions in physics: the role of anchoring intuitions and analogical validity. In J. D. Novak (Ed.), *Proceedings of the Second International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, III*, pp. 84–97 (Cornell University, Ithaca).

CURTIS, R. V. and REIGELUTH, C. M. (1984). The use of analogies in written text. *Instructional Science, 13*, 99–117.

DREISTADT, R. (1968). An analysis of the use of analogies and metaphors in science. *The Journal of Psychology, 70*, 97–116.

DUIT, R. (1991). On the role of analogies and metaphors in learning science. *Science Education, 75*, 649–672.

DUPIN, J. J. and JOHSUA, S. (1989). Analogies and 'modeling analogies' in teaching. Some examples in basic electricity. *Science Education, 73*, 207–224.

ERICKSON, F. (1986). Qualitative methods in research on teaching. In M. C. Wittrock (Ed.), *Handbook of Research on Teaching* (3rd ed). New York, Macmillan.

GABEL, D. and SHERWOOD, R. D. (1984). Analysing difficulties with mole concept tasks by using familiar analog tasks. *Journal of Research in Science Teaching, 21*, 843–851.

GAGNE, R. M. (1970). *The Conditions of Learning*. New York, Holt, Rinehart & Winston.

GENTNER, D. (1980). *The Structure of Analogical Models in Science*. Cambridge, MA, Bolt, Beronek and Neman.

GENTNER, D. (1983). Structure-mapping: a theoretical framework for analogy. *Cognitive Science, 7*, 155–179.

GENTNER, D. (1988). Analogical inference and analogical access. In A. Prieditis (Ed.), *Analogica*. Los Altos, Morgan Kaufmann, pp. 63–88.

GENTNER, D. and GENTNER, D. R. (1983). Flowing waters or teaming crowd: mental models of electricity. In D. Gentner and M. Stevens, (Eds), *Mental Models*. Hillsdale, NJ, Lawrence Erlbaum, pp. 99–128.

GLYNN, S. M. (1989). The teacher-with-analogies (TWA) model: Explaining concepts in expository text. In K. D. Muth (Ed.), *Children's Comprehension of Narrative and Expository Text: Research into Practice*. Newark, DE, International Reading Association.

GLYNN, S. M., BRITTON, B. K., SEMRUD-CLIKEMAN, M. and MUTH, K. D. (1989). Analogical reasoning and problem solving in science textbooks. In J. A. Glover, R. R. Ronning and C. R. Reynolds (Eds), *A Handbook of Creativity: Assessment, Theory, and Research*. New York, Plenum.

MERRIAM, S. B. (1988). *Case Study Research in Education–A Qualitative Approach*, San Francisco, Jossey Bass.

RADFORD, D. L. (1989). Promoting learning through the use of analogies in high school biology textbooks. Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco.

RUMELHART, D. E. and NORMAN, D. A. (1981). Analogical processes in learning. In J. R. Anderson (Ed.), *Cognitive Skills and their Acquisition*. Hillsdale, NJ, Lawrence Erlbaum, pp. 335–359.

SHAPIRO, M. A. (1985). Analogies, visualization and mental processing of science stories. Paper presented to the Information Systems Division of the International Communication Association, Honolulu, HI.

STAVY, R. (1991). Using analogy to overcome misconceptions about conservation of matter. *Journal of Research in Science Teaching, 28*, 305–313.

SUTULA, V. D. and KRAJCIK, J. S. (1988). The effective use of analogies for solving mole problems in high school chemistry. Paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA.

TIERNEY, D. S. (1988). How teachers explain things: metaphoric representation of social studies concepts. Paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA.

VOSNIADOU, S. and ORTONY, A. (1989). Similarity and analogical reasoning–a synthesis. In S. Vosniadou and A. Ortony (Eds), *Similarity and Analogical Reasoning*. New York, Cambridge University Press, pp. 1–17.

WEST, L.H.T. and PINES, A. L. (1985). *Cognitive Structure and Conceptual Change*. Orlando, Academic Press.

ZEITOUN, H. H. (1984). Teaching scientific analogies: a proposed model. *Research in Science and Technological Education, 2*, 107–205.